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Reconnaissance geology of the Ishash quadrangle, sheet 26/39C,  
Kingdom of Saudi Arabia

by

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This report is preliminary and has not been reviewed for conformity with  
U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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RECONNAISSANCE GEOLOGY OF  
ISHASH QUADRANGLE, SHEET 26/39 C,  
KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

The Ishash quadrangle occupies an area of about 2,725 km<sup>2</sup> on the northern border of the Precambrian shield in north-central Saudi Arabia between lat 26°00' and 26°30' N. and long 39°00' and 39°30' E. The northern quarter is covered by Cambrian Siq Sandstone and the southeastern corner is covered by Quaternary to Tertiary basalt. The remainder of the area is underlain by trachyandesite, andesite, and meta-sedimentary rocks of the lower part of the Hulayfah group and rhyolitic flows and tuffs of the upper part of the Hulayfah group. These rocks have been intruded by rocks that range in composition from gabbro to alkali-feldspar granite. Two small outcrops of Tertiary rhyolite are present in the quadrangle.

The predominant structures are folds and faults initiated by the formation of the caldera in the southwestern part of the area. The northerly trending structures were reactivated during the late Precambrian Najd orogenic event and again in the Tertiary during the opening of the Red Sea.

No mineral deposits of economic importance were found in the quadrangle.

INTRODUCTION

The Ishash quadrangle, sheet 26/39 C, occupies an area of about 2,725 km<sup>2</sup> on the northern border of the Precambrian shield in north-central Saudi Arabia between lat 26°00' and 26°30' N. and long 39°00' and 39°30' E. (fig. 1). The northern quarter of the quadrangle is covered by Cambrian Siq Sandstone whereas the southeastern corner is covered by Quaternary to Tertiary basalt of Harrat Khaybar. The remainder of the area is underlain by of trachyandesite, andesite, and metasedimentary rocks in the lower part of the Hulayfah group and rhyolitic flows and tuffs in the upper part of the Hulayfah group. These rocks have been intruded by rocks that range in composition from gabbro to alkali-

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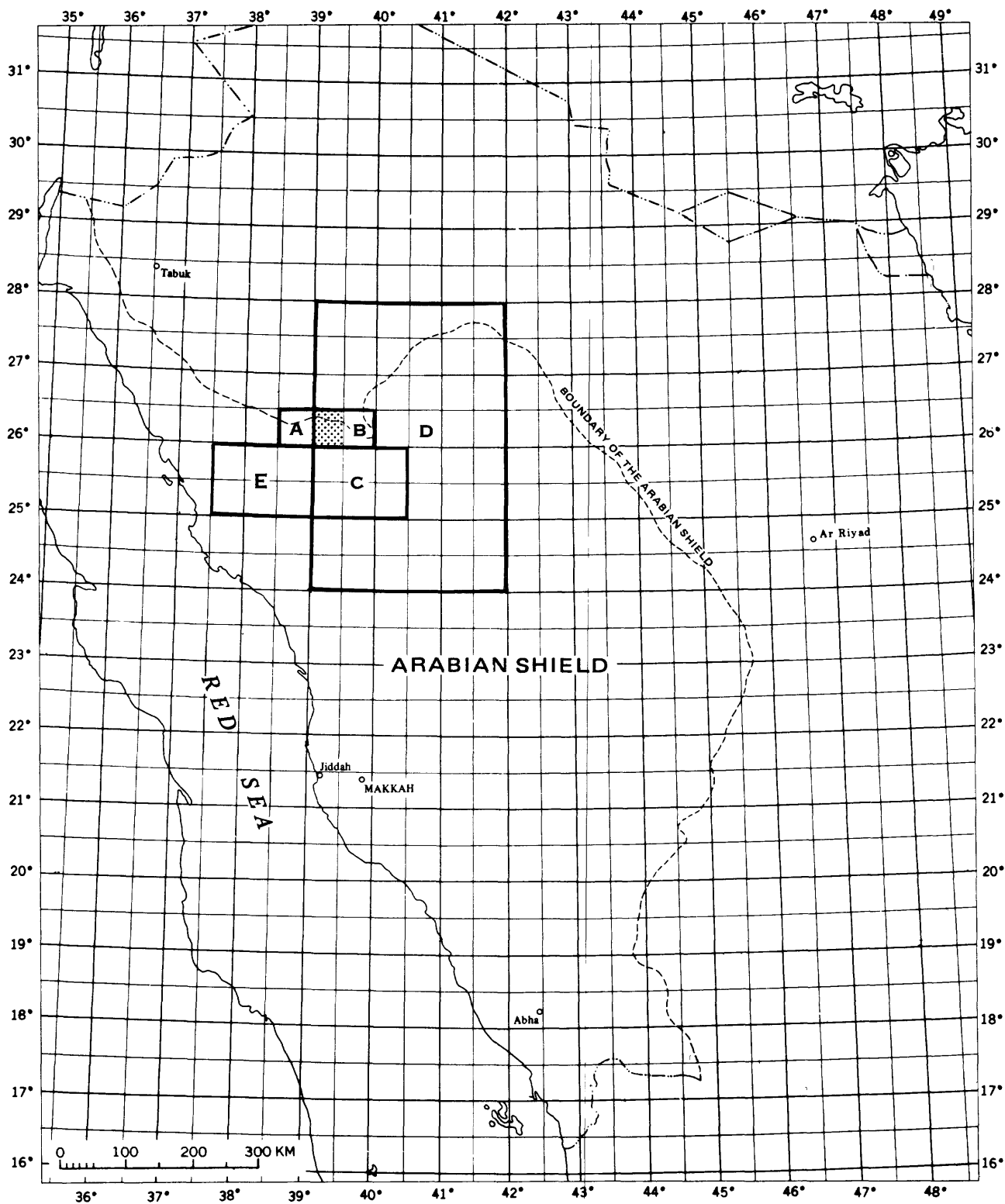


Figure 1.--Index map of western Saudi Arabia showing location of Ishash quadrangle (shaded) and other quadrangles referred to in this report: A, Qa'lat as Sawrah (Hadley, 1975); B, Jabal Khatam (Fairer, 1983); C, Khaybar (Dhellemmes and Delfour, 1979); D, Northeastern Hijaz (Brown and others, 1963); E, Wadi al 'Ays (Kemp, 1979).

feldspar granite. Tertiary volcanic rocks are present as rhyolitic tuff near the southeastern corner and rhyolite in the north-central part of the quadrangle. Unconsolidated surficial deposits fill the valleys.

Access in the quadrangle is excellent because the paved road from Al Madinah to Tabuk passes through the central part of the quadrangle from south to north. Also crossing the southeastern corner of the quadrangle is the paved road from Khaybar to Al Ula.

Previous geologic mapping of this quadrangle was done at a scale of 1:500,000 by Brown and others (1963). Work in the immediate area has been done by Kemp (1981), Dhellemmes and Delfour (1979), and Hadley (1975). Mapping for this report was accomplished by helicopter during November 1981 and March 1982. The work on which this report is based was performed in accordance with a work agreement between the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia and the U.S. Geological Survey (USGS).

#### PRECAMBRIAN GEOLOGIC SETTING

Precambrian rocks of the Hulayfah group underlie most of the southern three-quarters of the quadrangle. Hulayfah group as used in this report is correlative with the Al Ays group (Dhellemmes and Delfour, 1979; Kemp, 1981) and the Halaban group (Hadley, 1975). Hulayfah group is used here because of proximity to the type locality of Hulayfah and to provide continuity with the 1:250,000-scale mapping project.

The Hulayfah group is composed of metasedimentary and metavolcanic rocks that are the product of subsea eruptions, rapid transport and deposition of volcanic debris by turbidity currents, and subaerial explosive eruptions and deposition of ash-flow and ash-fall tuff. Rocks in the western part of the quadrangle tend to be massive to thick-bedded and coarse-grained agglomerates, volcanic flows, and tuffaceous rocks whereas rocks in the eastern and central parts of the quadrangle are composed mostly of thin, discontinuous beds of fine-grained, sedimentary rock intercalated with thick andesite and trachyandesite flows or sills.

Intrusive rocks include the Far granodiorite, mafic plutonic rocks, quartz diorite, tonalite, hornblende granite, monzogranite, hypabyssal granite, and alkali-feldspar granite.

# PRECAMBRIAN SEDIMENTARY, VOLCANIC, AND METAMORPHIC ROCKS

## Hulayfah group

The Hulayfah group in the Ishash quadrangle is composed of trachyandesite to andesite flows, sills, and pillow lavas intercalated with andesitic graywacke, agglomerate, marble, shale sandstone, conglomerate, and rhyolitic flows and tuffs. Most of the rocks are metamorphosed to lower greenschist facies and characteristically contain chlorite, epidote, and calcite. The basal part of the rhyolitic rocks tends to be keratophyric, possibly having been altered by the reaction with seawater shortly after being deposited.

In this report lithologic unit names of andesitic rock (ha), metasedimentary rock (hs), marble (hma), rhyolite (hr), rhyolitic ash-flow tuff (hrt), and rhyolitic ash-fall tuff (hra) will be used except where distinct units of formational rank are projected into the area from adjoining quadrangles.

## Thaa formation

Rocks of the Thaa formation (ht) crop out near the southwestern border of the quadrangle and are a continuation of similar rocks mapped in the Qal'at as Sawrah quadrangle (Hadley, 1975). These rocks consist of medium-bedded, fine-grained, gray to greenish-gray andesitic graywacke, greenish-gray argillite, and minor metaquartzite.

The anticline in the Thaa formation mapped in the Qal'at as Sawrah quadrangle (Hadley, 1975) is mapped as an anticline breached by gabbro of the mafic plutonic rock unit in this quadrangle. Because of a gap of about 1.5 km between the photocomposite bases of the two 1:100,000-scale quadrangles, the border cannot be resolved; however, this discrepancy is resolvable between the 1:250,000-scale maps whose borders do match.

## Matran formation

The Matran formation (hm), composed of metamorphosed andesitic flow rock, agglomerate, and tuff, crops out in the west-central part of the quadrangle near the boundary with the Qal'at as Sawrah quadrangle. These rocks in part may correlate with Hulayfah andesite and trachyandesite that crop out in the eastern part of the quadrangle. Only the upper part of the formation is exposed and is conformably and unconformably overlain by rhyolite breccia, flows, and tuffs of the Hulayfah group (Jizl formation of Hadley, 1975).

In outcrop the rocks consist of thick, even beds of

greenish-gray, porphyritic to nonporphyritic andesite separated by beds of andesitic tuff and agglomerate. Amygdules are common but are more prevalent in the nonporphyritic flow rocks. The material that fills the amygdules consists of epidote, calcite, chlorite, and quartz.

No samples of this unit were collected in the quadrangle, but rocks collected immediately to the west in the Qal'at as Sawrah quadrangle were described by Hadley (1975) as consisting of labradorite, augite, hornblende, and olivine phenocrysts in a matrix of calcic oligoclase to sodic andesine microlaths. Greenschist metamorphism of these rocks has produced ubiquitous epidote, chlorite, and sphene. Olivine is altered to serpentine, and augite is altered to actinolite.

### Andesite

Andesite and trachyandesite flow rock, agglomerate, tuff, and sills (ha) are common in the central and western parts of the quadrangle. These rocks are thought to correlate in part with the Matran formation, although a direct correlation cannot be made across the caldera located in the southwestern part of the quadrangle.

In the eastern part of the quadrangle these rocks consist of trachyandesite flows and plugs in sparse, discontinuous outcrops interspersed with outcrops of coarse graywacke and sparse, thin beds of black marble. The trachyandesite consists of large, broken and partially resorbed plagioclase and quartz phenocrysts in a matrix of microlaths of plagioclase, potassium feldspar, and anhedral quartz.

Andesite of the east-central part of the quadrangle is comprised of flow rock, agglomerate, andesitic tuff, and possibly some sills that are intercalated with Hulayfah sedimentary rocks and marble.

Thick sills and (or) flows of andesite are intercalated with the rhyolitic rocks associated with the caldera that occupies the southwestern part of the quadrangle.

In thin-section the andesite has a pilotaxitic to pan-idiomorphic granular texture and consists of plagioclase and sparse augite phenocrysts in a matrix of plagioclase, potassium feldspar, and quartz. Actinolite and tremolite, epidote, chlorite, calcite, and sphene are common propylitic alteration minerals. Microbreccia, lapilli, and flow textures are commonly preserved.



## Sedimentary rocks

Sedimentary rocks (hs) of the Hulayfah group are composed of graywacke, phyllite, conglomerate, slate, quartzite, and marble. Graywacke is dark green to greenish gray, fine to medium grained or agglomeratic, and commonly is schistose or phyllitic. Thin, discontinuous beds of slate are variegated red, gray, and greenish gray to black. Sparse, thin beds of quartz wacke are intercalated with the slate. Also common are thin beds of white recrystallized marble.

Marble (hma) is black, gray, and buff, thin-bedded or platy to massive, and very siliceous. Grain size ranges from fine to very coarse, and the rock commonly is a recrystallized breccia. Thin to thick veins of white calcite are common.

## Rhyolitic rocks

Rhyolitic rocks that in part correlate with the Jizl formation (Hadley, 1975) occur in the upper part of the Hulayfah group as flow rock (hr), ash-flow tuff (hrt), and ash-fall tuff (hra) and were erupted from a caldera located in the southwestern part of the quadrangle. The rhyolitic rocks are not included in the Jizl formation in this quadrangle because their contact with the underlying Matran formation can be traced only to the edge of the caldera. In general these rocks, especially the tuffaceous rocks, tend to be keratophyric, possibly because of reaction with seawater during subaqueous eruptions. In this reaction potassium was replaced by sodium.

Rhyolite.--In thin section rhyolite flow rock (hr) consists of small broken phenocrysts of plagioclase, microcline, resorbed quartz, spherulites of plumose tridymite, and sparse biotite in a flow-textured matrix of devitrified glass that contains quartz, potassium feldspar, and iron oxide. Zircon, muscovite, calcite, epidote, and allanite are common accessory minerals. Commonly granophyric intergrowths of quartz and potassium feldspar are present. The phenocrysts tend to be glomeroporphyritic. Chlorite commonly occupies interstices between grains, and chlorite, calcite, and quartz fill the lithophysae. Piemontite phenocrysts are found in some flows on the northern side of the caldera.

Rhyolitic ash-flow tuff.--Ash-flow tuffs including tuff breccia (hrt) surround and fill the caldera. These tuffs are thick bedded to massive and are nonwelded to densely welded or vitrophyric. Commonly, thin ash-fall tuff beds separate the ash-flow unit. Attitudes observed on the units within the caldera and near its margin tend to be chaotic.

In thin section the ash-flow tuff consists of a matrix of shards, pumice, lithic fragments (predominantly andesite), and phenocrysts of rounded, broken and partially resorbed quartz, plagioclase, and potassium feldspar. Secondary minerals include pyrite, calcite, epidote, piemontite, chlorite, and sericite. Chlorite occurs as grass-green, greenish-gray, and tobacco-brown varieties. All glass in the microcrystalline felsite matrix has been completely devitrified. Foliate (eutaxitic) structure of flattened tricusate shards is ubiquitous, and fiamme or pipernoid structures are common in the densely welded units.

Ash-flow tuff exposed in the central to northwestern parts of the quadrangle has undergone intensive cataclastic deformation to form quartz sericite schist. In thin section the matrix of this rock has been recrystallized to an equigranular mosaic of quartz and potassium feldspar. Relic phenocrysts of plagioclase and quartz are strained and re-aligned parallel to the structural grain. Sericite occupies interstices parallel to the structural grain and imparts the sheen and schistosity observed on hand specimens.

Rhyolitic ash-fall tuff.--Ash-fall tuff (hra) occurs near the top of the rhyolite section and is well exposed on the southern edge of the caldera. These deposits consist of unconsolidated to poorly consolidated, crudely to well-stratified beds of white, porous rhyolitic pumice and small, angular fragments of rhyolite and rhyolitic welded tuff.

In thin section pumice fragments account for as much as 95 percent of the rock. This pumice consists of glass-walled, undeformed, hollow vesicles and displays no evidence of collapse. The size of the pumice fragments ranges from 1 mm to as much as 30 mm in longest dimension. Angular fragments of rhyolite range in size from 1 mm to as much as 10 mm, and locally fragments as large as 30 mm were found.

One 3-m-thick bed of ash-fall tuff consists of shards and angular fragments of rhyolite but no pumice. This well-graded deposit probably was reworked by water, which transported the pumice and deposited it elsewhere.

Rhyolitic rocks interpreted to be part of the Murdama group were mapped as unconformably overlying the Al Ays group (Hulayfah group of this report) in the Khaybar and Wadi al 'Ays quadrangles (Dhellemmes and Delfour, 1979; Kemp, 1981). A close examination of these rocks revealed no apparent unconformity; densely welded rhyolitic ash-flow tuff conformably overlies moderately welded rhyolitic ash-flow tuff. The fact that radiometric signatures of total count potassium, thorium, and uranium measured on the rocks are essentially the same for both units indicates that they probably were erupted from the same magma source.

## PRECAMBRIAN INTRUSIVE ROCKS

### Far granodiorite

The Far granodiorite (fgd) [name modified from the Wadi al Far granodiorite of Hadley, 1975 in accordance with the Saudi Arabian Lithostratigraphic Code] was named for outcrops in Wadi al Far in the Qal'at as Sawrah quadrangle (Hadley, 1975). This narrow body of rock forms a flat valley near the southwestern corner of the quadrangle. All exposures are deeply weathered and covered with guss except where in close proximity to erosion-resistant diabase and basalt dikes. In hand sample the rock is a uniform, medium- to coarse-grained granodiorite that consists of plagioclase, potassium feldspar, quartz, and accessory biotite and hornblende.

Stratigraphic relationships to the overlying rhyolitic and andesitic rocks could not be determined in this quadrangle because of extremely poorly exposed outcrops. Hadley (1975) mapped this body as a post-Hulayfah unit that intruded the Matran formation.

### Mafic plutonic rocks

Small intrusions of mafic plutonic rock (mpr) crop out on the western border and central part of the quadrangle. In this quadrangle the rocks are gabbroic; however, Hadley (1975) also identified hornblende, diorite, quartz diorite, and granodiorite in outcrops immediately to the west in the Qal'at as Sawrah quadrangle. In outcrop the mafic plutonic rocks are massive, dark gray to black, and moderately sheared. Contact relationships indicate that they are small, pod-shaped intrusions into the rhyolites of the Hulayfah group.

### Tonalite

Three small tabular bodies of tonalite (to) crop out in the quadrangle near the southeastern corner, and on the northeastern and southeastern borders. The rock is fine to medium grained and is composed of plagioclase, and quartz with secondary chlorite, epidote, and calcite. Outcrops in the western part of the quadrangle tend to be pervasively sheared. The body near the southwestern corner is not sheared, and it domed the andesite that it intruded.

Stratigraphic relationships between the three bodies are not known, but it is presumed by the author that all were emplaced simultaneously in the waning stages or immediately after the cessation of eruption of the Hulayfah rhyolitic volcanic rocks. These tonalites may be hypabyssal granite

altered by the same potassium-sodium exchange that affected the rhyolite, or they may be a later, entirely unrelated intrusion.

### Quartz diorite

Quartz diorite (qd) intrudes Hulayfah andesite and sedimentary rocks in the east-central part of the quadrangle. This rock is composed of plagioclase, quartz, and minor potassium feldspar, having hornblende and augite as essential mafic minerals. The rock is fine to medium grained and contains poikilitic plagioclase and granophyric quartz-potassium feldspar intergrowths. Uralitic hornblende, epidote, chlorite, and sericite are common greenschist-facies alteration minerals. Feldspars are strongly saussuritized.

Quartz diorite is intruded by granitic dikes that may be related to the alkali-feldspar granite pluton located approximately 6 km to the east, but only one dike is shown at map scale.

### Dacite

Dacite (da) occurs in three widely separated outcrops in the quadrangle. The rock is dark to medium-gray and contains large eroded and broken phenocrysts of potassium feldspar and minor plagioclase in a cryptocrystalline felsic matrix. Accessory minerals include primary epidote and piemontite, allanite, and magnetite. Alteration minerals include uraltic hornblende, epidote, chlorite, and calcite. All potassium feldspar phenocrysts are saussuritized. These alteration minerals indicate greenschist-facies metamorphism or auto-metamorphism.

The stratigraphic relationship of these rocks is not clear. In the outcrop near the eastern border the dacite intrudes andesite but is intruded by silicic rocks. In the outcrop near the southwestern corner dacite intrudes both the Thaa formation and rhyolitic ash-flow tuff of the Hulayfah group. Therefore the rock is post-Hulayfah but pre-silicic intrusive in age.

### Biotite-muscovite monzogranite

Centrally located in the quadrangle is a double-lobed pluton of biotite-muscovite monzogranite (mg) that intrudes Hulayfah group andesite and sedimentary rocks. The monzogranite is reddish brown to buff and white, coarse grained, and is composed of approximately equal proportions of plagioclase and potassium feldspar crystals having anhedral quartz,

perthite, biotite, and muscovite in the interstices. Chlorite is rare. Some granophyric intergrowths of quartz and potassium feldspar are present and indicate that the rock probably was emplaced at a shallow depth. This body has steep sides that sharply cross-cut the host rocks. Possibly this rock correlates in part with hypabyssal granite that crops out in close proximity to the west and northwest.

#### Hornblende granite

Hornblende granite (hbg) crops out at several localities in the southeastern part of the quadrangle. This rock is medium gray to greenish gray, fine to coarse grained, hypidiomorphic granular to glomeroporphyritic, and consists of potassium feldspar, plagioclase, and quartz and hornblende, kaersutite, rare augite and biotite, magnetite, apatite, and zircon. Greenschist-facies alteration minerals include chlorite, urallite, epidote, calcite, sphene, and sericite. Potassium feldspar is strongly saussuritized, and magnetite is commonly oxidized to hematite. Quartz content ranges from nil to 10 percent and the amount of plagioclase ranges from 30 to 60 percent. The average composition is that of a monzogranite. Contact relationships indicate that the hornblende granite intrudes rocks of the Hulayfah group.

#### Hypabyssal granite

Fine-grained, quench-textured granite and aplite (hg) intrude Hulayfah group rocks throughout the western half of the quadrangle. These rocks are light gray and reddish gray to white and are composed of quartz, tridymite, plagioclase, and potassium feldspar. Granophyric textures, myrmekite, perthite, and hollow plagioclase are common and indicate the hypabyssal emplacement of these rocks. Muscovite and sparse zircon are ubiquitous. Epidote (pleiomite), chlorite, and small veins of calcite are rare. Because these rocks are intimately associated with the Hulayfah group rhyolites, it is probable that they are in part shallow intrusions of the magma from which the rhyolites were derived.

In the northwestern part of the quadrangle, rhyolite and hypabyssal granite are cataclastized, and it is very difficult to distinguish between them.

#### Alkali-feldspar granite

A large pluton of hypersolvus alkali-feldspar granite (ag) crops out in the northeastern part of the quadrangle. This pluton is composed of coarse-grained, pink, grussy weathering granite that has intruded trachyandesite of the

## Hulayfah group.

In thin section the granite is composed predominantly of strained perthite and quartz and accessory biotite, sphene, magnetite, apatite, and rare zircon. Alteration minerals are sparse and consist of sericite, chlorite, and hematite commonly located along microfractures. The texture is hypidiorhombic granular and the maximum grain size is approximately 6 mm. Strain is readily apparent on a microscopic and megascopic scale. All minerals in thin section show strain extinctions and kinking or bending of crystal lamellae. On a megascopic scale the pluton has a conspicuous joint pattern.

Near the southeastern corner of the quadrangle occurs a kapuka composed of alkali-feldspar granite, which has been intruded by thick diabase sills in the Jabal Khatam quadrangle adjacent to the east (Fairer, 1983). This alkali-feldspar granite body is similar to the previously described granite except that very late stage plagioclase crystals that replace part of the perthite are present. The outermost exposures on the edge of the body are very fine grained, have a quench or hypabyssal texture, and contain tridymite, hollow plagioclase, and graphic intergrowths of quartz and feldspar.

### Silicic intrusive rock

White, very fine grained, saccharoidal, silicic intrusive rock (si) is associated as a late-stage intrusion with alkali-feldspar granite in the northeastern part of the quadrangle and with Hulayfah group rhyolite and ash-fall tuff in the southwestern part. The rock is composed predominantly of quartz and small amounts of potassium feldspar and muscovite.

### Basaltic and aplitic dikes

East-trending basaltic and aplitic dikes intrude all Precambrian rocks in the quadrangle. These dikes are very fine grained and generally form ridges above the more weathered and eroded older rocks.

## PALEOZOIC ROCKS

### Siq Sandstone

The flat-lying Siq Sandstone (Gs) of Cambrian age (Bramkamp and others, 1956; Powers and others, 1966) unconformably overlies Precambrian rocks in the northern part of the quadrangle. The underlying erosional surface generally has little relief. Where exposed in the quadrangle, the Siq Sandstone consists of dark-red, reddish-brown, and buff, fri-

able, medium-grained to conglomeratic, thickly bedded and strongly crossbedded quartz sandstone. Sparse quartz pebbles in the sandstone are gray, white, and brown, well rounded, and polished. Matrix material of the conglomerate and the nonconglomeratic beds of the Siq Sandstone consist of well-sorted, subangular to rounded grains of arkosic minerals cemented by quartz and calcite.

The long tongue of Siq Sandstone, which occurs in the north-central part of the quadrangle, was thought by Brown and others (1963) to be bounded by faults as part of a graben structure. Mapping in this quadrangle revealed that no faults are present and that the tongue of sandstone occupies a swale in the underlying paleotopography.

It has long been recognized that the Siq Sandstone was deposited during an extensive early Cambrian marine transgression (Powers and others, 1966). In the Qal'at as Sawrah quadrangle to the west (Hadley, 1975), the presence of fossil trilobite burrows and gastropod tracks in mud-cracked sandstone indicates deposition of the Siq Sandstone in shallow water.

## CENOZOIC ROCKS

### Rhyolite flow and rhyolitic tuff

In the north-central part of the quadrangle, one rhyolite flow (Tr) is located on top of the erosional surface developed on the lower part of the Siq Sandstone. The rhyolite has a flow-textured, devitrified matrix of potassium feldspar and quartz and contains phenocrysts of quartz and potassium feldspar. Sparse sericite and hematite are alteration minerals.

One hill consisting of brecciated rhyolitic tuff (Trt) crops out near the edge of the harrat in the southeastern corner of the quadrangle. The rock is reddish brown, vitric, and has a eutaxitic texture. Phenocrysts include quartz and potassium feldspar; large pumice fragments are common. Very fine grained, vitric, maroon, and dark-reddish-brown rhyolitic dikes and very fine grained, brown granitic dikes anastomose throughout the outcrop.

These rhyolites crop out along a northwest-trending line drawn between Jabal Abyad in the Khaybar quadrangle (Dhellemmes and Delfour, 1979), through the rhyolitic tuff near the southeastern corner of the Ishash quadrangle to the rhyolite flow in the north-central part of the quadrangle. This line is probably the trace of a concealed crustal weakness related to the late Precambrian Najd orogenic event (Schmidt and others, 1979; Greenwood and others, 1982).

## Basalt

Alkali-olivine basalt (QTb) of Harrat Khaybar occupies the southeastern corner of the quadrangle. This fine-grained, dark-greenish-gray to black basalt is composed of olivine, diopside, calcic plagioclase, ilmenite, and small amounts of nepheline and potassium feldspar (Coleman and others, <sup>unpub.</sup> data). Amygdules filled with calcite or zeolite are common. The pahoehoe-type flows are 2- to 5-m-thick and typically display poorly developed columnar jointing.

The basalt is overlain by the Tertiary rhyolite, but overlies some of the rhyolite in the Jabal Khatam quadrangle to the east (Fairer, 1983), where recent volcanic eruption has occurred.

## Surficial deposits, undivided

All valleys and other depressions in the quadrangle are covered by pediment, eolian sand, and alluvial sand, gravel, and cobble deposits (Qu). The material in these deposits was derived from the surrounding outcrops.

## METAMORPHISM

Greenschist-facies metamorphism of the Precambrian andesitic volcanic and sedimentary rocks of the Ishash quadrangle is characterized by the presence of uralitic hornblende, chlorite, epidote, calcite, albite, and quartz. This low-temperature hydrothermal metamorphism was enhanced by the catalytic influence of seawater entrapped during subaqueous eruptions (Williams and others, 1954). Hulayfah rhyolites and rhyolitic tuffs tend to be keratophyric and possibly the exchange of potassium for sodium occurred by the same mechanism of low-temperature hydrothermal alteration.

Evidence suggesting high heat or pressure is rare; however, the presence of actinolite in the vicinity of the granitic intrusions indicates a higher grade of metamorphism.

## STRUCTURE

Structures in the Ishash quadrangle consist primarily of faults and folds associated with the development of the caldera located in the southwestern part of the quadrangle and the emplacement of the post-eruptive plutonic rocks. Faults radiate from and surround the caldera but have a preferred northerly trend. Attitudes observed in close proximity to the caldera are chaotic and indicate block rotation. The boundary of the caldera is indicated by an abrupt change in attitude, grain size, and a large increase



in the amount of brecciation in the rocks. Within the caldera, breccia blocks as large as 100 m were found. Unpublished aeromagnetic and aeroradiometric data indicate a deep alluvial-filled hole that coincides with the caldera (M. D. Kleinkopf, oral commun., 1983).

Movement on the north-trending faults probably was re-activated during the late Precambrian Nadj orogenic event (Brown, 1972; Schmidt and others, 1979; Greenwood and others, 1982) when the schistosity of the rocks in the west-central part of the quadrangle developed and again during the Tertiary opening of the Red Sea when these faults localized the venting of basaltic and rhyolitic magma (Dhellemmes and Delfour, 1979; Coleman and others, unpub. data)

An examination of aeromagnetic and aeroradiometric data also indicates a strongly developed northerly structural trend.

#### ECONOMIC DEPOSITS

No mineral deposits of economic importance were found in the quadrangle, and no entries were made to the Mineral Occurrence Documentation System (MODS) data bank.

#### DATA STORAGE

The sample location map for the Ishash quadrangle has been data filed under USGS-DF-03-14 in the Jiddah office of the U.S. Geological Survey Saudi Arabian Mission.

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